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Operation Heli-STAR - Effects of Buildings on Helicopter Noise

Krishan Ahuja
Robert Funk
Jeffrey Hsu
Michael Heiges
Charles Stancil

Georgia Tech Research Institute
Atlanta, Georgia 30332

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16. Abstract

Operation Heli-STAR (Helicopter Short-Haul Transportation and Aviation Research) was established and operated in Atlanta, Georgia, during the period of the 1996 Centennial Olympic Games. Heli-STAR had three major thrusts: 1) the establishment and operation of a helicopter-based cargo transportation system, 2) the management of low-altitude air traffic in the airspace of an urban area, and 3) the collection and analysis of research and development data associated with items 1 and 2. Heli-STAR was a cooperative industry/government program that included parcel package shippers and couriers in the Atlanta area, the helicopter industry, aviation electronics manufacturers, the Federal Aviation Administration (FAA), the National Aeronautics and Space Administration (NASA), and support contractors.

Several detailed reports have been produced as a result of Operation Heli-STAR. These include 4 reports on acoustic measurements and associated analyses, and reports on the Heli-STAR tracking data including the data processing and retrieval system, the Heli-STAR cargo simulation, and the community response system. In addition, NASA's Advanced General Aviation Transport Experiments (AGATE) program has produced a report describing the Atlanta Communications Experiment (ACE) which produced the avionics and ground equipment using automatic dependent surveillance-broadcast (ADS-B) technology. This latter report is restricted to organizations belonging to NASA's AGATE industry consortium. A complete list of these reports is shown on the following page.

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Operation Heli-STAR Technical Reports

Volume 1 DOT/FAA/ND-97/9	Operation Heli-STAR - Summary and Major Findings; S. Fisher, FAA AND-710, Washington DC and E. McConkey, Science Applications International Corporation, Arlington, Virginia; Principal Editors; September 1997
Volume 2 DOT/FAA/ND-97/10	Operation Heli-STAR - Helicopter Noise Levels Near Dekalb Peachtree Airport; Krishan Ahuja, Robert Funk, Jeffrey Hsu, Marcie Benne, Mary L. Rivamonte, and Charles Stancil; Georgia Tech Research Institute, Atlanta, Georgia; September 1997
Volume 3 DOT/FAA/ND-97/11	Operation Heli-STAR - Helicopter Noise Annoyance Near Dekalb Peachtree Airport; Krishan Ahuja, Marcie Benne, Mary L. Rivamonte, Robert Funk, Jeffrey Hsu, and Charles Stancil; Georgia Tech Research Institute, Atlanta, Georgia; September 1997
Volume 4 DOT/FAA/ND-97/12	Operation Heli-STAR - Helicopter Noise at Heliports; Krishan Ahuja, Robert Funk, Jeffrey Hsu, and Charles Stancil; Georgia Tech Research Institute, Atlanta, Georgia; September 1997
Volume 5 DOT/FAA/ND-97/13	Operation Heli-STAR - Effects of Buildings on Helicopter Noise; Krishan Ahuja, Robert Funk, Jeffrey Hsu, Michael Heiges, and Charles Stancil; Georgia Tech Research Institute, Atlanta, Georgia; September 1997
Volume 6 DOT/FAA/ND-97/14	Operation Heli-STAR - Aircraft Position Data; Michael Heiges, Shabnam Khan; Georgia Tech Research Institute, Atlanta, Georgia, September 1997
Volume 7 DOT/FAA/ND-97/15	Operation Heli-STAR - Cargo Simulation System; Ellen Bass, and Chasles Stancil; Georgia Tech Research Institute, Atlanta, Georgia, September 1997
Volume 8 DOT/FAA/ND-97/16	Operation Heli-STAR - Community Involvement; Christine Eberhard and Bobbi Rupp; CommuniQuest, Inc., Manhattan Beach, California; September 1997
Volume 9 DOT/FAA/ND-97/17	Operation Heli-STAR - Atlanta Communication Experiment (ACE), AGATE Flight Systems Communication Work Package 1.4, (AGATE Restricted Information) (AGATE Flight Systems Communication Team), December 1996.

FOREWORD

This is Volume 5 of a 9-volume report documenting the activities and results of Operation Heli-STAR, the Atlanta Short-Haul Transportation System (ASTS). ASTS was a cooperative government/industry program that established a helicopter transportation system to support community of Atlanta during the 1996 Olympic games. Volumes 2 through 5 of this set of reports documents the noise studies that were performed during Operation Heli-STAR. The noise research was performed by Georgia Tech Research Institute (GTRI). GTRI also produced two additional reports documenting Operation Heli-STAR. Volume 6 describes the aircraft position data processing research, and Volume 7 documents a Cargo Simulation System that was used in support of Heli-STAR cargo operations. The research and development elements of Operation Heli-STAR were funded by the Federal Aviation Administration through Science Applications International Corporation (SAIC).

The GTRI manager of the overall ASTS program was Mr. C. Stancil. The Principal Investigator of the noise studies, reported in volumes 2 through 5, was Dr. K. K. Ahuja of GTRI. GTRI personnel responsible for making and analyzing day-to-day noise measurements were Dr. R. Funk and Mr. Jeff Hsu who were assisted by a team of 20 researchers. Ms. Marcie Benne, a graduate student from the School of Psychology lead the effort on the community survey reported in Volume 2. She was assisted by Ms. Mary Lynn Rivamonte, a student in the School of Aerospace Engineering. The authors are particularly grateful for Dr. Mike Heiges of GTRI for providing the helicopter altitudes and flight paths and to Mr. Stephen Williams, also of GTRI, for setting up the microphone locations for noise contour measurements.

The titles of the four volumes reporting noise research are:

Volume 2 - Helicopter Noise Levels Near Dekalb Peachtree Airport

Volume 3 - Helicopter Noise Annoyance Near Dekalb Peachtree Airport

Volume 4 - Helicopter Noise at Heliports

Volume 5 - Effects of Buildings on Helicopter Noise

The titles of the other two volumes authored by GTRI are:

Volume 6 - Aircraft Position Data

Volume 7 - Cargo Simulation System

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EXECUTIVE SUMMARY

The Heli-STAR demonstration project during the 1996 Olympic Games in Atlanta, Georgia, provided the opportunity of making detailed noise measurements of the Federal Aviation Administration's (FAA) S-76 helicopter. A massive amount of data was acquired using this aircraft at a helipad constructed in support of the project and using the ARNAV local data-link system with embedded GPS to track the aircraft during the testing. The purpose of these measurements was to be able to do the following:

- Measure real-time contours of the aircraft at a large number of ground locations during fly-over.
- Study the effects of varying approach parameters (approach speed, approach angle, weight) on the noise signature.
- Study the effects of various terrain features on measured noise. These features include natural features such as hills and man-made features such as buildings.
- Record as much data as possible for more detailed studies at a later date.

A test plan consisting of five noise measurement site configurations and eighteen approaches for each configuration was carried out. The expectation is that data from the five noise measurement configurations can be integrated to form detailed moving noise footprint maps of this particular helicopter. To this end, one microphone was kept at the same location for all test configurations to allow for minor variations in flight altitudes. All raw data from these tests is currently archived and some preliminary data analysis was accomplished. Real-time noise contours of the helicopter operation were constructed from the data of one run, during one landing operation. The repeatability at the common location has been examined for a limited number of runs. Much additional work remains to integrate the multiple configurations into a common footprint.

Terrain effects were examined via measurement configuration that included measurement locations at the base of buildings, on the roof of the buildings, and in areas to the opposite side of the helipad from the buildings. Preliminary results indicate a noise reduction due to terrain masking. These results indicate that earthen hills and building walls can be used to mask helicopter noise, when the helicopter is near and on the pad. A more detailed study of the data is required.

SECTION 1

OBJECTIVE

The objective of this study was to measure the real-time noise contours of a helicopter performing various approaches. Additionally, a helipad site containing a mixture of terrain features and buildings was desired to attempt to quantify the effects of reflections and attenuation due to terrain shielding.

Control of various parameters of the helicopter approach profile were done to study their effects on the noise footprint of the aircraft. The parameters varied were:

- approach speed
- approach angle
- weight
- takeoff: hover in ground effect or out of ground effect

The acoustic data were logged by the sound level meters and recorded on digital audio tapes (DAT) for later analysis.

SECTION 2

BACKGROUND

2.1 Introduction to Noise Metrics

An introduction to the noise metrics used in this document is included here. The acoustical metrics described here are sound pressure level (dB), A-weighted sound pressure level (dBA), and equivalent continuous sound level (Leq).

2.1.1 Sound pressure level (dB)

Sound is transmitted through the air by sound waves which are small oscillations in pressure. Impingement of these pressure oscillations on the ear produce the sound we hear. The sound waves can be characterized by two properties: the frequency of oscillation, measured in Hertz (Hz) and the sound pressure level measured in decibels (dB).

Sound pressure level is a ratio of the sound pressure of a source to a reference pressure. The reference pressure is 20 micropascals, the threshold of hearing. Decibels are a logarithmic scale of sound pressure level. The normal range of sound pressure levels encountered is from about 30 dB to 100 dB in everyday sounds.

It is important to stress the logarithmic nature of the sound pressure level. This prevents using simple addition when summing noise levels. For instance, if two noise sources each produce 100 dB individually, when operated together they don't produce 200 dB but 103 dB. Each doubling of the noise results in a 3 dB increase in the total. This also occurs when adding sources when one is much higher than the other. If an 80 dB source and a 100 dB source are operated together the resulting level would still be 100 dB. The louder source masks the quieter one. This holds true for sources with more than 12 dB difference.

2.1.2 A-weighted sound pressure level (dBA)

An important characteristic of sound is its frequency. This is rate at which sound pressure fluctuations are sensed by the ear. It is expressed in cycles per second or Hertz (Hz). The normal frequency range of hearing for most people extends from a low frequency of about 20 Hz to a high frequency between 10 and 15 kHz. But the sensitivity

to these frequencies is not uniform. People are most sensitive to frequencies in the range of normal conversation, typically from 1000 to 2000 Hz. People are much less sensitive to lower frequencies and somewhat less sensitive to higher frequencies. A filter, called an A-weighting filter, is used to weight different frequencies according to the sensitivity of the human ear at those frequencies. This filter is applied to the linear output of a microphone system to more accurately reflect the level of the sound sensed by the human ear. Because this filter generally matches the sensitivity of the human ear, sounds having higher A-weighted sound levels are judged to be louder than those with lower A-weighted sound levels, a relationship which might not otherwise be true. It is for this reason that A-weighted sound levels are normally used to evaluate environmental noise sources.

Because of the correlation with human hearing, the A-weighted sound pressure level has been adopted as the basic measure of environmental noise by the Environmental Protection Agency (EPA).

2.1.3 Equivalent Continuous Sound Level (Leq)

The sound pressure level is an instantaneous measure of the noise level that varies with time. The Equivalent Continuous Sound Level, abbreviated Leq, is a measure of the exposure resulting from the accumulation of sound levels over a particular period of interest -- for example, a minute, an hour, or a full 24-hour day. The sound levels may be weighted and normally, for environmental measurements, A-weighting is used. Because the length of the period can be different depending on the time frame of interest, the applicable period should always be identified or clearly understood when discussing the metric. Such durations are here represented as $Leq_{(1\ min.)}$. The environmental mode used on the sound level meters employed in this study was able to log 1 minute or 1 second Leq's.

Conceptually, Leq may be thought of as a constant sound level over the period of interest that contains as much sound energy as the actual time-varying sound level with its normal peaks and valleys. It is important to note, that, if heard, the two signals (the constant one and the time-varying one) would sound very different from each other. Also, recalling the previous description of the addition of sound levels, be aware that the "average" sound level suggested by Leq is not an arithmetic mean, but a logarithmic, or "energy-averaged" sound level. Comparable to the addition of decibels, this means that higher A-weighted sound levels receive greater emphasis than lower values. For

example, if the sound level is 50 dBA for 30 minutes, followed by 100 dBA for the next 30 minutes, then the Leq for the entire hour is 97 dBA -- not the 75 dBA that we might expect. Thus, loud events clearly dominate any noise environment described by the metric.

SECTION 3

TEST SETUP AND METHODOLOGY

3.1 Test Description

The availability of the twenty-one noise monitoring setups for DNL testing described in Volume 1 of this report and the ability to have dedicated flights of the Federal Aviation Administration (FAA) S-76 aircraft provided an opportunity of making detailed measurements of noise contours in a setting with varying terrain features, including buildings. The Communication, Navigation and Surveillance (CNS) which has an imbedded Global Positioning System (GPS) used for the Heli-STAR program was used in tracking the subject helicopter. A number of temporary helipads, constructed for the Heli-STAR program, were available for the testing without fear of interference from other Georgia operations. A helipad behind the Atlanta Journal-Constitution printing plant in Norcross, Georgia, was chosen and is described in section 3.2 below.

This test set-up was used to record sound levels in landing operations for various approach angles and speeds. Noise levels were measured at a total of one hundred locations around the helipad. Only twenty-one noise measuring systems were available. The strategy of acquiring noise data at 100 locations, therefore, consisted of making measurements at 21 locations first for a given set of helicopter maneuvers. Twenty of the twenty-one microphones were then moved to another twenty locations. One microphone was kept at the same location to track variations in noise levels due to minor variations in ambient conditions. Repeating this procedure five times provided noise data at a total of 100 locations (and a reference location) at which detailed noise contours could be constructed.

3.2 Test Location

3.2.1 Atlanta Journal-Constitution Printing Plant, Norcross (NOR)

All noise measurements for this portion of the study were made in vicinity of a temporary helipad located in the parking area behind the Atlanta Journal-Constitution Printing Plant in Norcross, northeast of Atlanta. The helipad was set up to support the Heli-STAR demonstration during the 1996 Olympic Games in Atlanta. The three letter reference for this location was NOR. This location was chosen for a number of reasons. It was under exclusive control of the Heli-STAR program, so there would be no

interference from other operations during testing. The pad was located in an industrial area, so a large number of flights could be scheduled without bothering a residential neighborhood. The site also provided for noise monitoring at a variety of locations: near buildings, in open fields, and rooftops. Figure 3.1 is an aerial photograph of the helipad and the surrounding area. The approach path is labeled on the figure. The normal approach to this pad consisted of a flyover of the pad followed by a turn to intercept the approach path. The main features of the surrounding terrain are the railroad tracks running across the approach path, the printing plant, and an open field behind the parking area.

3.2.2 Noise Measurement Locations

A large number of test locations were envisioned for this task. A grid, aligned with the flight path, was constructed on the approach to the helipad. The grid was laid out on fifty-foot centers to the extent allowed by natural obstacles. Locations on the grid were labeled with a format consisting of a letter and one or two numbers. The letters were R, L, and C denoting a location to right, left, or on the centerline of the approach path facing the helipad. The first number indicated the distance back along the approach path, the second, the distance to the left or right of the approach path. Distances past the pad were shown in parenthesis. For example, R150-250 would be a location 150 feet back from the pad and 250 feet to the right of the approach path. A centerline location would be noted as C250, a location 250 feet back along the approach path. Additional locations were located along the powerline easement to the right of the approach path, the access road to the field behind the printing plant, and the roof of the printing plant.

Figure 3.2 is a diagram of the site and the measurement locations. Due to limited equipment and personnel, the tests were done in five configurations of locations. One location, C250, was used in all the tests as a repeatability check. Figures 3.3 (a)-(e) show the groups of locations used for each of the five test configurations.

3.3 Test Equipment

3.3.1 Sound level monitoring equipment overview

This testing was accomplished with the same portable sound level monitoring setups used in the noise studies around the Dekalb-Peachtree Airport helipad and described in Volume 2 of this report. Each setup consisted of a sound level meter and a battery pack in a waterproof case and a tripod with a wind screen and rain protection for

the microphone. A digital audio tape (DAT) recorder was supplied to record raw data. Each person in charge of the data acquisition was also given a beeper used to signal acquisition start and stop times.

Each noise measurement setup consisted of the following components:

- CEL Type 1 Sound Level Analyzer Model 573 or 593
- CEL - 527 Preamplifier
- CEL - 250 Type 1, 1/2" Electret microphone
- Sony TCD-D8 DAT tape recorder
- CEL - 284/2 Type 1 acoustic calibrator
- 5 meter microphone extension cable
- CEL - 594 wind and rain protection system for microphone
- tripod
- rechargeable battery
- weather-resistant case

Three types of meters were used: CEL-573.A1, CEL-573.C1, and CEL-593.C1. All meters had A and C weighting filters. The CEL-573.C1 and CEL-593.C1 also included octave and third octave filters. Each meter was equipped with an internal clock to time stamp the acquired data and had a raw, line-level output from the microphone suitable for recording. The DAT recorder also contained an internal clock which time stamped the audio data recorded on the tape. Up to twenty-one of these setups were used in the testing. The microphone and preamplifier were mounted on a tripod and protected by wind and rain gear.

3.3.2 Sound level meter operation and parameters measured.

All Sound Level Meters (SLM's) were equipped with a feature to allow acquisition of Leq values for time intervals of less than one second. This feature was called FASTORE by the manufacturer. The FASTORE mode was used in this test to acquire Leq values over a 100 ms time interval. Additionally all data were recorded on DAT for later analysis.

Operationally the meters were run as follows:

1. All meter clocks were synchronized to Naval Observatory Master Clock time each morning. The clock in the DAT recorder was also synchronized at this time. This was to provide a link between the noise measurements and the time-stamped GPS track data of the helicopter.

2. One operator was assigned to each measurement setup. The equipment was setup at the assigned location. The microphone was mounted five feet from the ground and the SLM case was moved away from the microphone location to minimize interference.
3. A calibrator was used to calibrate the SLM and the calibration signal was recorded on the DAT recorder for a level reference.
4. The SLM was set in FASTORE mode to log 100 ms A-weighted Leq values.
5. The SLM and DAT were started manually at a signal from the beeper. This signal was sent by a person in contact with the operations center and notified of the impending arrival of the test aircraft.
6. The SLM was checked periodically during the data acquisition to ensure correct operation of the equipment.
7. Activity around the test location was recorded on log sheets by the test personnel, noting any abnormal occurrences.
8. The calibration of the equipment was checked at the conclusion of the acquisition and any deviation noted on the log sheet. An end calibration was also recorded on the DAT tape.

3.4 Communication, Navigation and Surveillance (CNS) Tracking

A tracking system developed by ARNAV, used in tracking aircraft for the Heli-STAR program, was also used in this study. It used a GPS receiver mounted on the aircraft to determine its position and transmitted that position data to a ground station. The system also had a facility for passing short messages. For this study, a portable ground station was set up near the helipad along with another GPS system to monitor and document the position of the ground station. This was done to ensure reception of the track data from the helicopter all the way to the ground. The ground station also allowed some communication with the flight test engineer on board the aircraft during testing.

The ARNAV system used a standard GPS receiver subject to the errors of selective availability. No differential GPS setup was available at the time to provide more precise tracking. Under the assumption that both the ground station and the aircraft were using the same set of satellites to determine position and thus would have the same errors, the known position of the ground station was used to correct the aircraft track data. Records made at the pad of takeoff and touchdown times, as well as radar data from PDK were used to verify and correct the GPS track data.

3.5 Testing Methodology

The FAA S-76, tail number N38, was the test aircraft. A matrix of runs was designed to vary approach speed, approach angle and aircraft weight. Three approach speeds, three approach angles and two weights were used. The weight parameter was varied due to fuel burn and presence of passengers. A set of approaches starting at high weight condition and a set starting at a lower weight condition were selected. Aircraft weight was recorded on board by the flight test engineer based on fuel weight passed from the pilots. Level flyovers at various speeds were also done as fuel allowed. A table of the flights for each measurement configuration is shown in Table 3.1. As was mentioned in the discussion about measurement locations, the test was done in five sets, denoted with flight cards A-E. The tests were scheduled based on the availability of the aircraft. Noise measurements corresponding to flight card A were carried out in the afternoon of 9 July 1996, flight cards B and C on 10 July 1996, and flight cards D and E on 17 July 1996.

Table 3.1 Flight matrix for each noise configuration.

Run Number	Airspeed (knots)	Approach Angle (degrees)	
1	100	8.0	Higher Weight
2	80	8.0	
3	60	8.0	
4	100	<8.0	
5	80	<8.0	
6	60	<8.0	
7	100	>8.0	
8	80	>8.0	
9	60	>8.0	
10	100	8.0	Lower Weight
11	80	8.0	
12	60	8.0	
13	100	<8.0	
14	80	<8.0	
15	60	<8.0	
16	100	>8.0	
17	80	>8.0	
18	60	>8.0	

SECTION 4

RESULTS AND DISCUSSION

4.1 Introduction

The massive amount of data acquired could not be analyzed within the scope of Heli-STAR. Some preliminary analysis was done, examining only a small subset of the data. Preliminary results presented here are some frames from a real-time contour measurement during Flight Card A, comparison of the common microphone location for the same run in each measurement configuration, and some results from measurements including the effects of terrain. Further analyses will be carried out in the future, subject to availability of funding to support the labor intensive effort to process the data.

4.2 Preliminary Contours from Fight Card A

The data from measurement configuration A was assembled in a large computer file having the measured Leq value at each time step for each measurement location. This along with the helicopter position data, was used to generate a moving contour showing the noise footprint measured on the ground and the position of the helicopter relative to the measurement locations. A movie was generated showing the variation of this noise with time. Presented here are four frames from that movie, as the helicopter approaches for landing on run 1 of flight card A. Figure 4.1 shows a range versus altitude plot of the helicopter approach, with the helicopter location for each of the noise contour plots indicated on the figure. Figure 4.2 shows a noise contour plot. The contours are of measured Leq(100ms). The axis system originates at the helipad and the axes are oriented to run north and east of the helipad. On the right side of the figure is a bar graph indicating the altitude of the helicopter. The large solid circle to the upper right of the plot indicates the helicopter position relative to the helipad. Ambient levels in the vicinity of the helipad were in the range of 55-65 dBA. Figures 4.3 through 4.5 show the effect on the noise contour as the helicopter nears the pad, with Figure 4.5 having the helicopter landed on the pad. Data presented in this fashion is useful in visualizing the changes in noise footprint due to changes in approach profile. It is possible to envision this type of information being available to the pilot such that noise profile could be managed by piloting changes to minimize noise.

4.3 Comparison of the C250 Location for All Flight Cards

In order to construct moving noise contours by combining the data from all measurement configurations, the continuity between each run over all configurations must be checked. Figure 4.6 shows the traces for run 4 for all configurations, with the timebase normalized to be the recorded touchdown time of the helicopter. The peaks on the left side of the graph are from the helicopter fly over before its turn onto final approach for landing. These exhibit scatter because the time between the flyover and the touchdown has varied by approximately 20 seconds over the different configurations. The traces converge as they near the time of touchdown and the peak levels encountered by the noise monitor are within 2 dB of each other. The third set of peaks on the figure correspond to the helicopter takeoff. They follow each other well with the exception of Card D.. During this run the helicopter went to a hover before moving forward, causing the higher level for a greater time. The close following of the time traces is encouraging. These need to be linked with the GPS position data to also check the approach profile.

4.4 Effects of Buildings and Terrain

The buildings and hills on the site allow for the examination of terrain features on the noise levels. Noise configuration D had measurement locations on the roof of the building at the base of the building and a corresponding location on the other side of the approach path. Figure 4.7 shows a comparison of locations to the left (L150-200) and right (R150-200) of the helipad on the ground and one on the roof above L150-200. The helipad was bounded on the right and behind by sloping hills approximately 10 to 12 feet high. Behind the helipad was a railroad track in a valley created by the hill behind the helipad and another, larger hill on the other side of the track. The R150-200 location was near the bottom of this far hill in the valley. Figure 4.7 also shows the time of pad flyover, touchdown and takeoff labeled on the plot. The edges of the plot show higher ambient noise at the roof location due to mechanical ventilation equipment on the roof. The flyover peak is at nearly the same value for all locations, but slightly higher for the R150-200 location because the flyover was to the right side of the pad. The minimum occurring after the flyover peak was when the helicopter was turning to line up on the approach. The R150-200 location has a lower noise level due to shielding by the hill between it and the helicopter. As the helicopter neared the pad the traces converged as all locations came in direct view of the helicopter. With all locations equally exposed, the levels are again very close to each other. As the helicopter landed, the hill behind the helipad shielded the R150-200 location, which can be seen in the steep drop off in the

noise level before touchdown. The roof location was near the edge closest to the helicopter and had direct exposure to the noise of the helicopter on the ground. Noise measured at the L150-200 location was attenuated by truck trailers in the parking lot. On takeoff, the traces again converged as all locations had direct line-of-sight to the helicopter.

Figure 4.8 concentrates on the takeoff portion of run 4 and adds an additional trace, Roof N4. Refer to Figure 3.3(d) for a diagram of the location. Due to its location on the roof it was shielded from the helipad by the building walls. The left hand side of Figure 4.8 is when the helicopter is on the pad. The levels are highest at the roof location above L150-200, next highest at L150-200, lower at R150-200 and lowest at Roof N4. When the helicopter lifted off, the same effects were seen as described for the previous figure. In this case, due to the greater distance of Roof N4 from the helipad as compared to the other locations, it does not have as high a peak level. Although, once the location is directly exposed to the noise from the helicopter, the Roof N4 trace follows the other three.

These results suggest noise reductions could be achieved by designing helipads so that terrain features can be used to mask the noise, whether it be earthen hills or erected walls. Noise levels at shielded locations will be the same for portions of the flight where they are directly exposed, but will be reduced when the helicopter is on the ground.

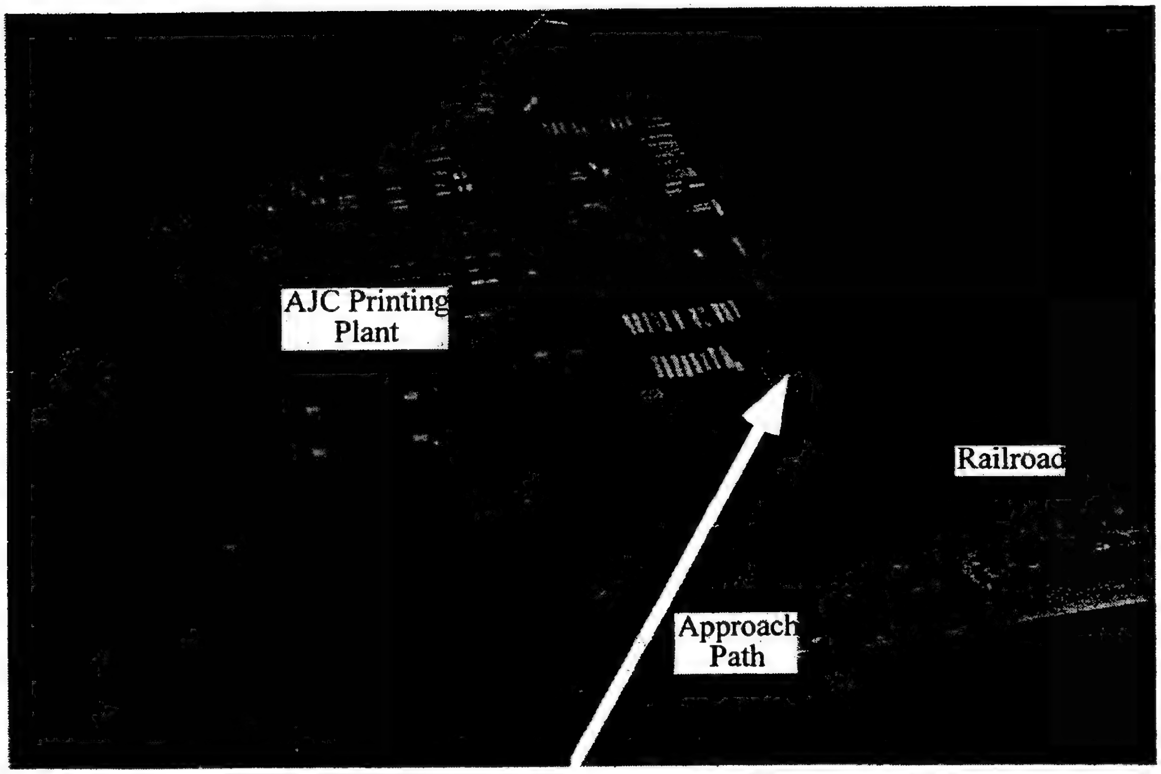


Figure 3.1: Aerial photograph of the NOR helipad.

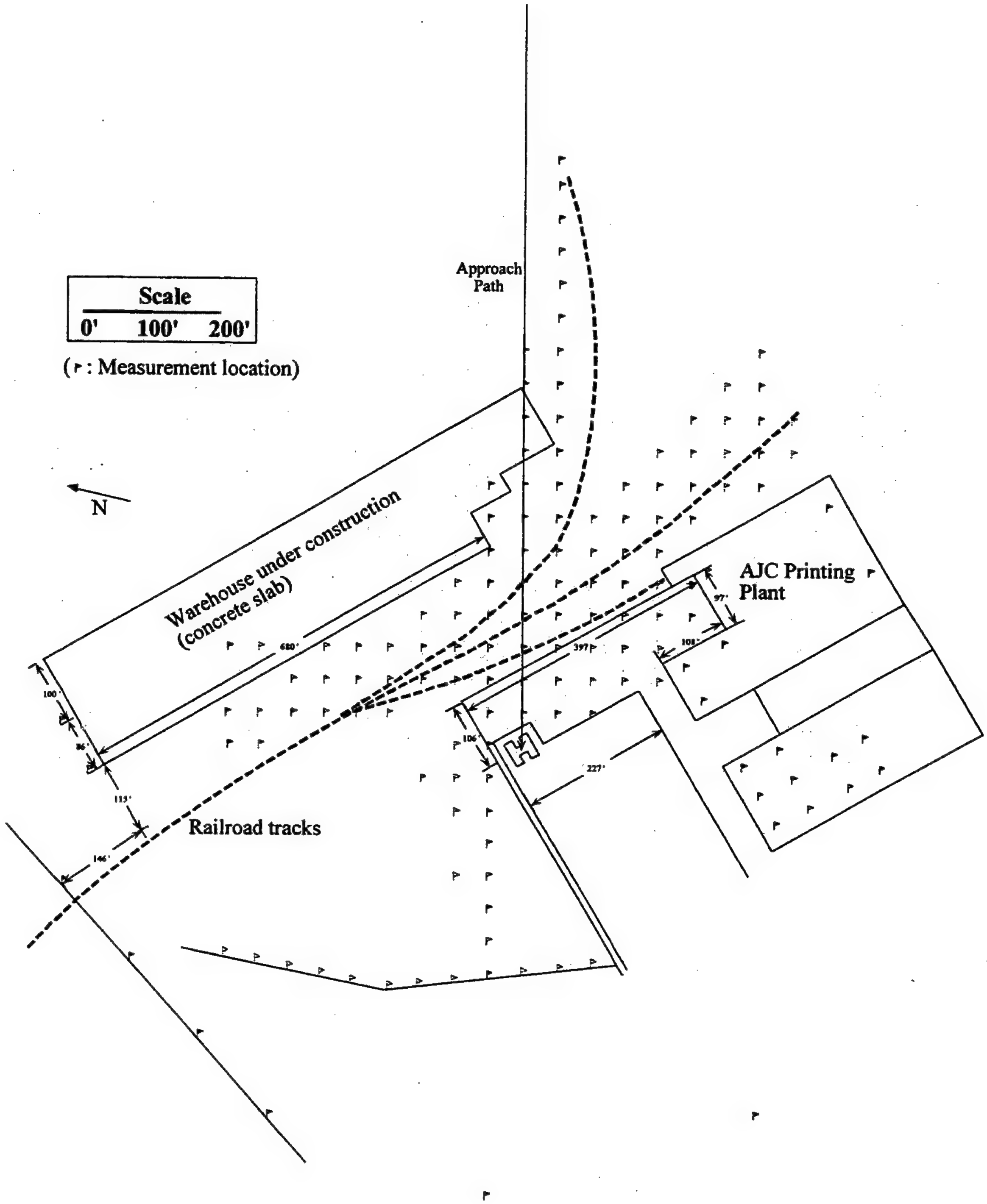
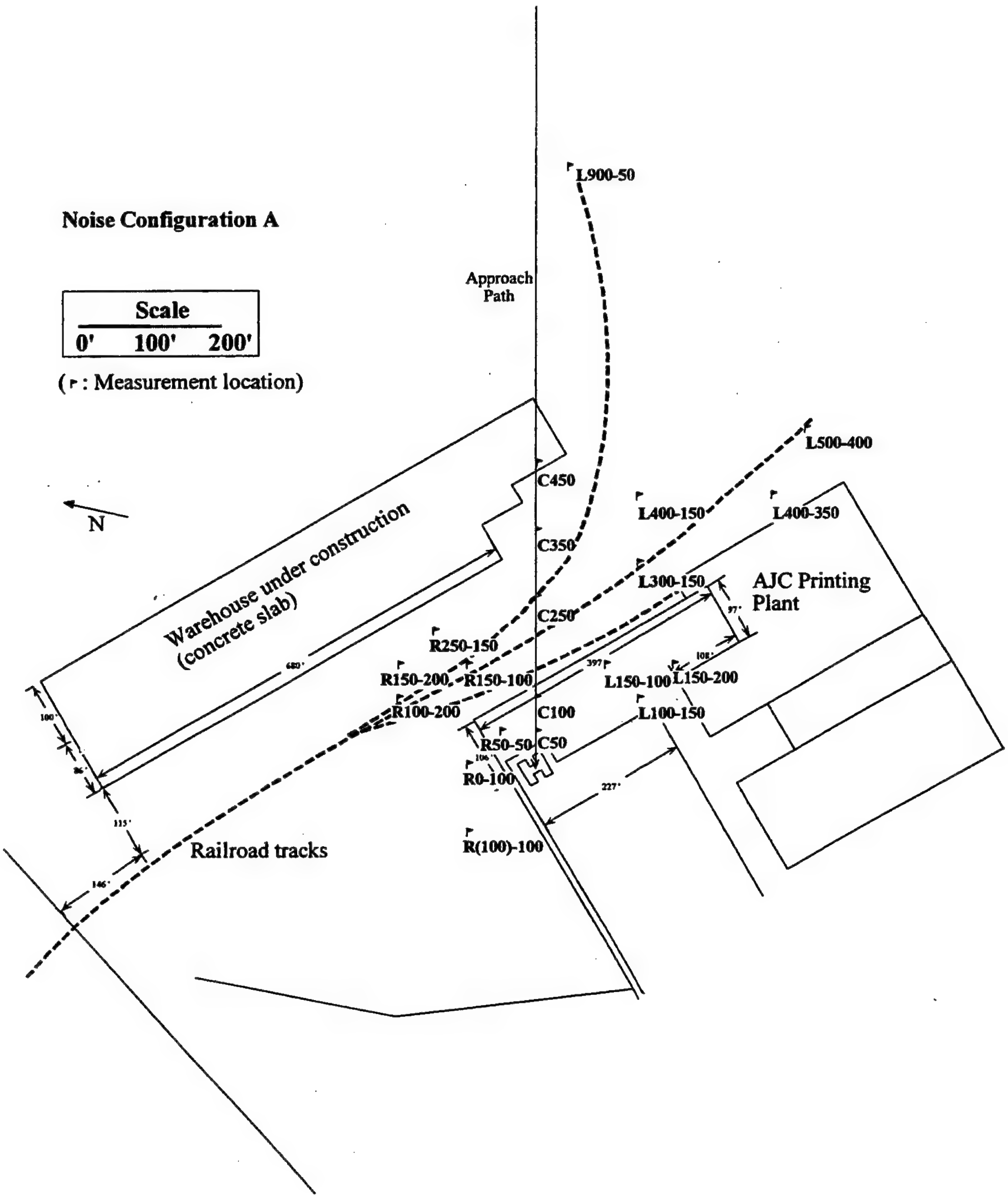
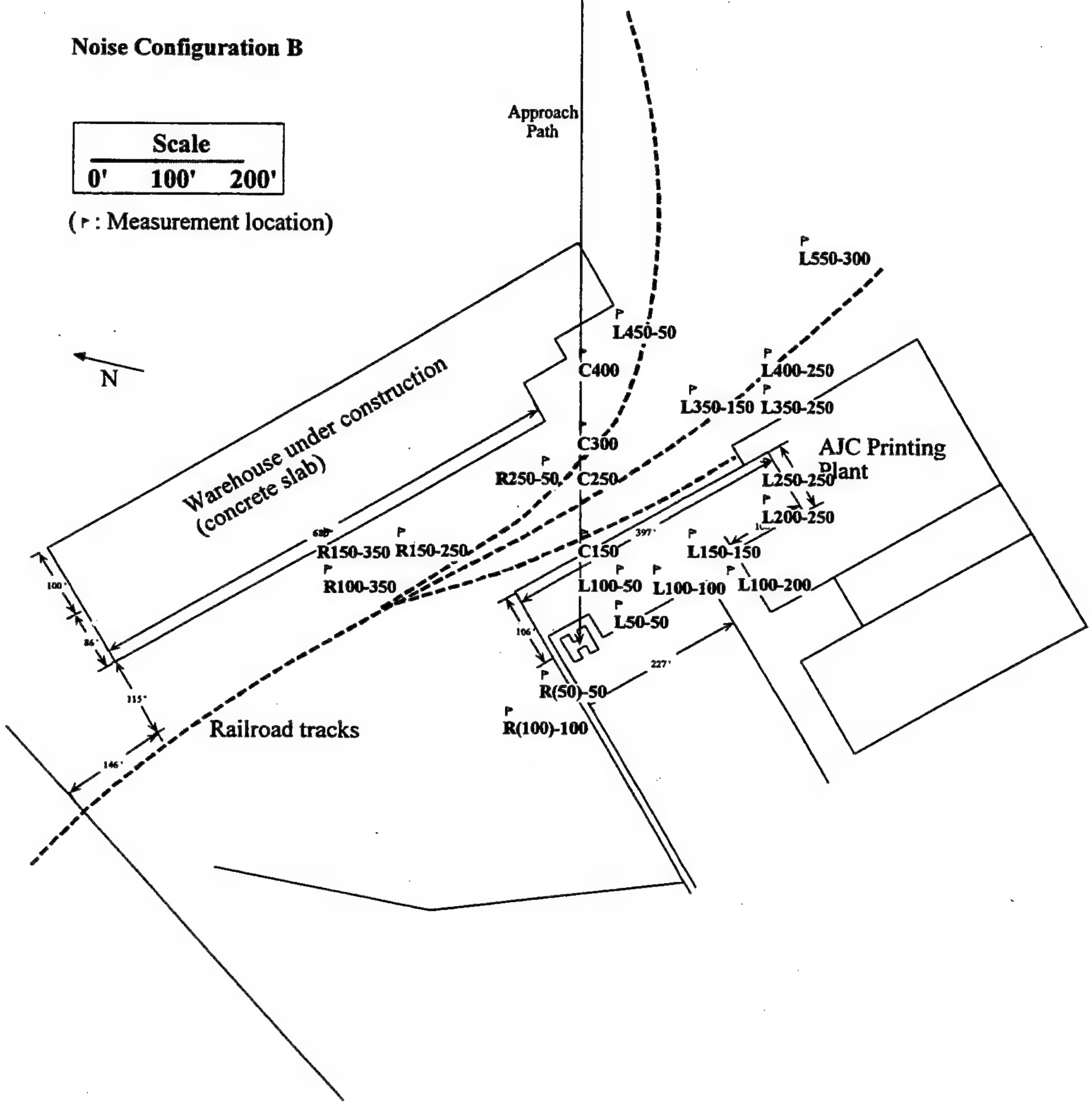


Figure 3.2: NOR Site diagram showing all measurement locations.



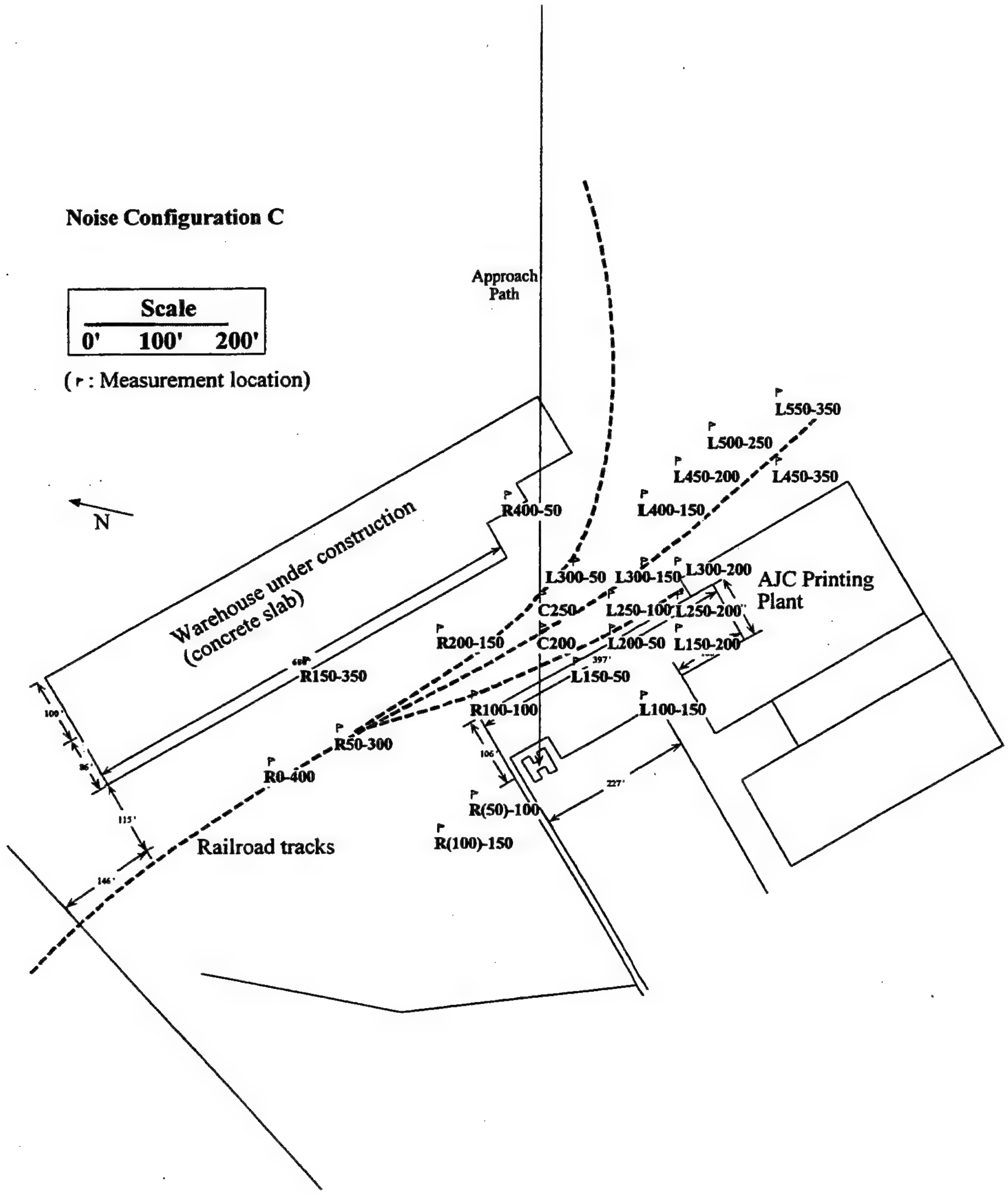
(a) Measurement Configuration A

Figure 3.3: Measurement locations used.



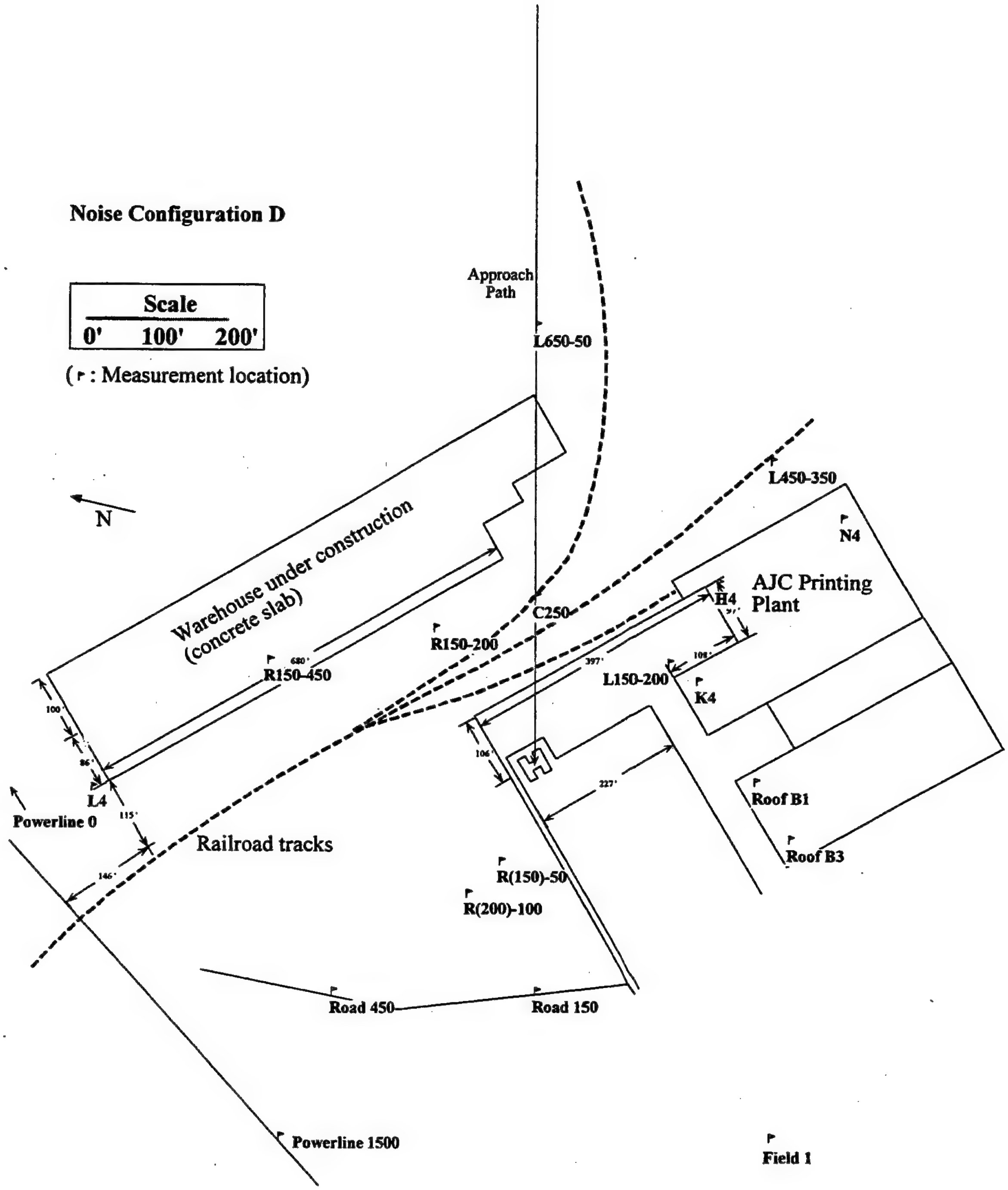
(b) Measurement Configuration B

Figure 3.3: (continued) Measurement locations used.



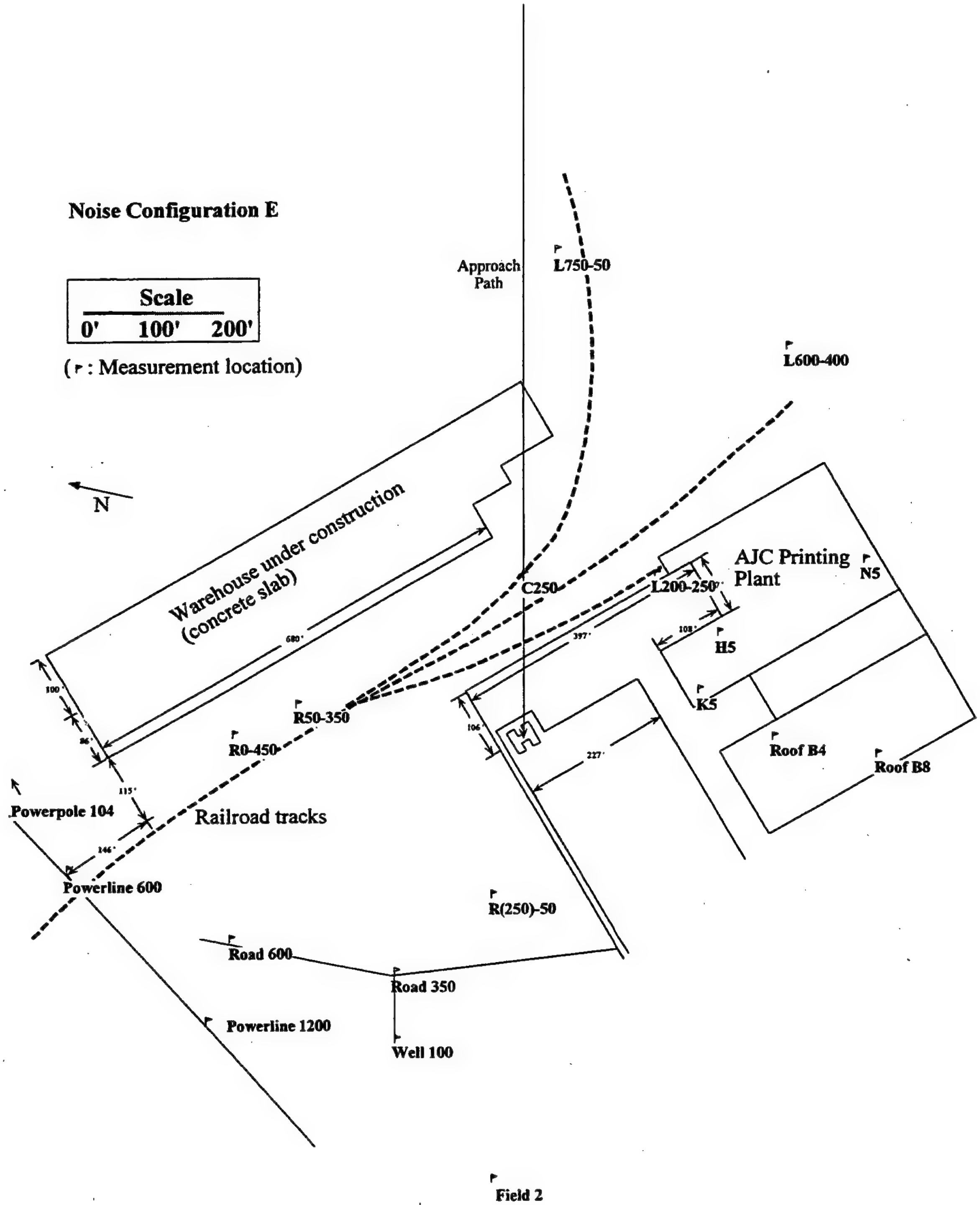
(c) Measurement Configuration C

Figure 3.3: (continued) Measurement locations used.



(d) Measurement Configuration D

Figure 3.3: (continued) Measurement locations used.



(e) Measurement Configuration E

Figure 3.3: (continued) Measurement locations used.

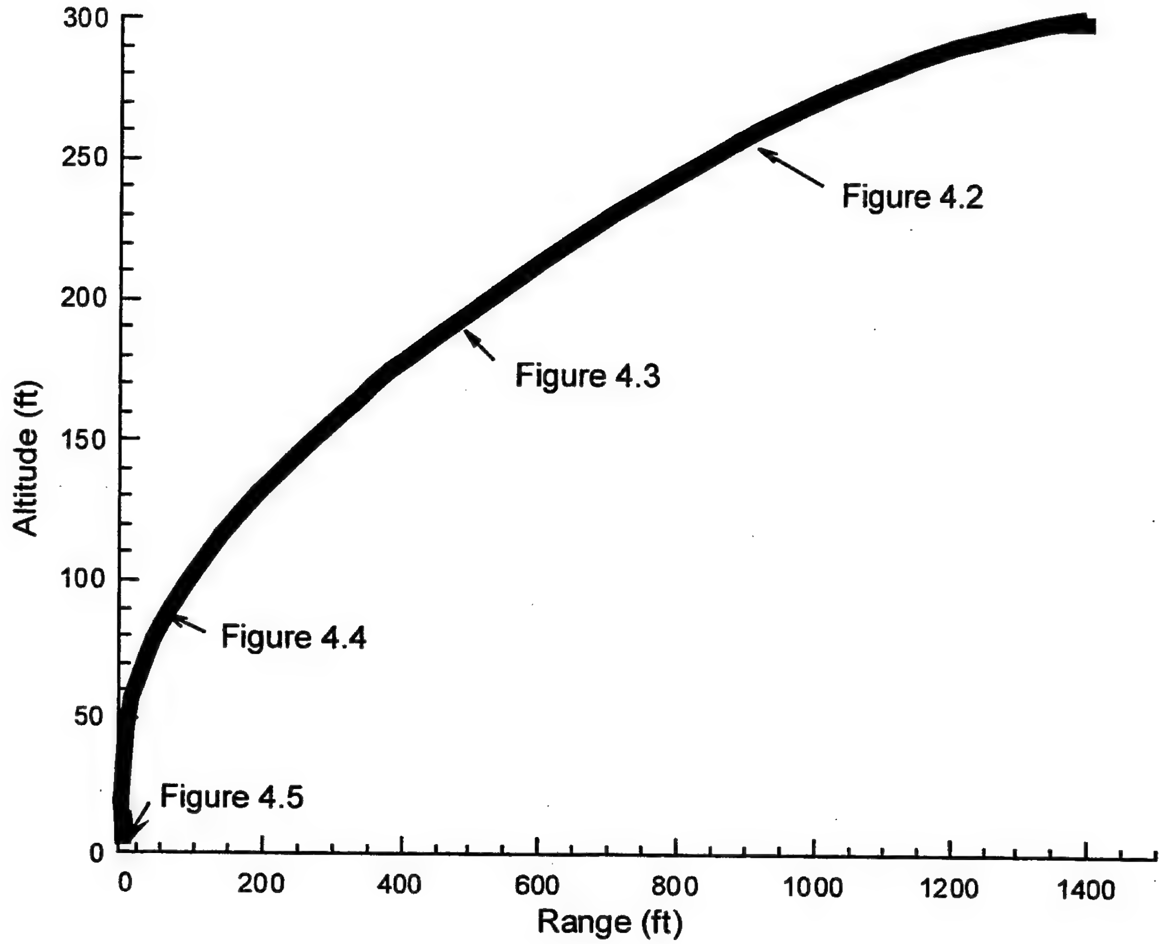


Figure 4.1: Range versus Altitude for Run 1, Measurement Configuration A.

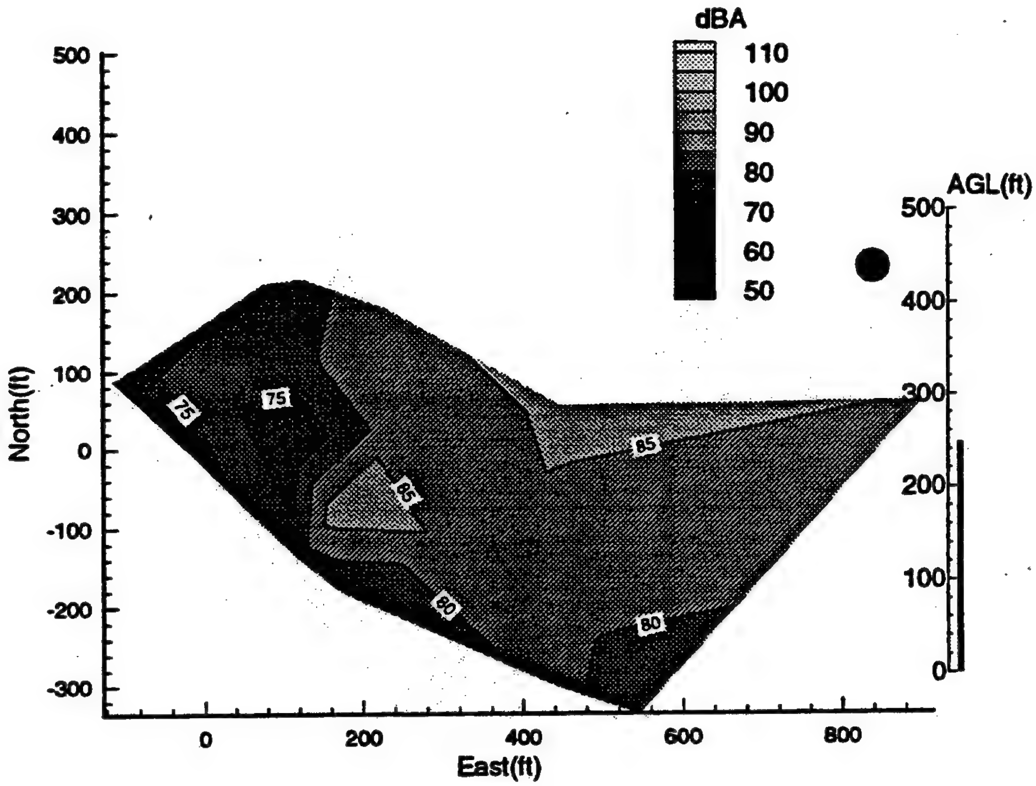


Figure 4.2: Noise contour for Run 1, Measurement Configuration A, range 900 ft.

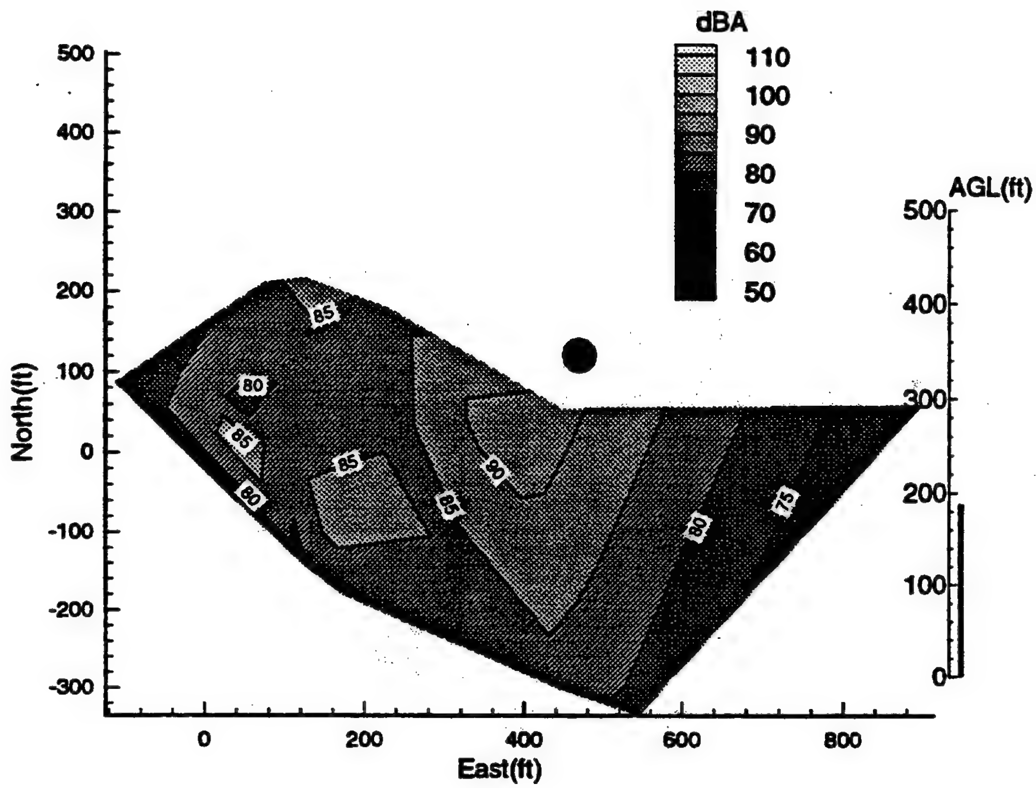


Figure 4.3: Noise contour for Run 1, Measurement Configuration A, range 500 ft.

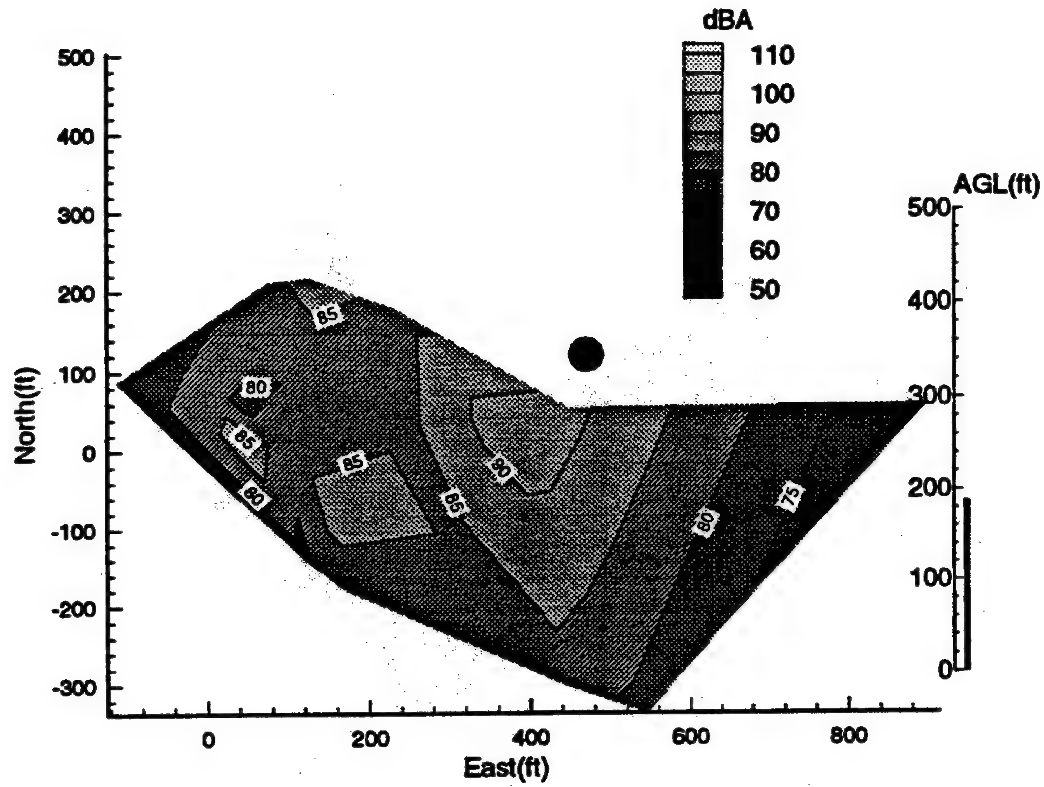


Figure 4.4: Noise contour for Run 1, Measurement Configuration A, range 50 ft.

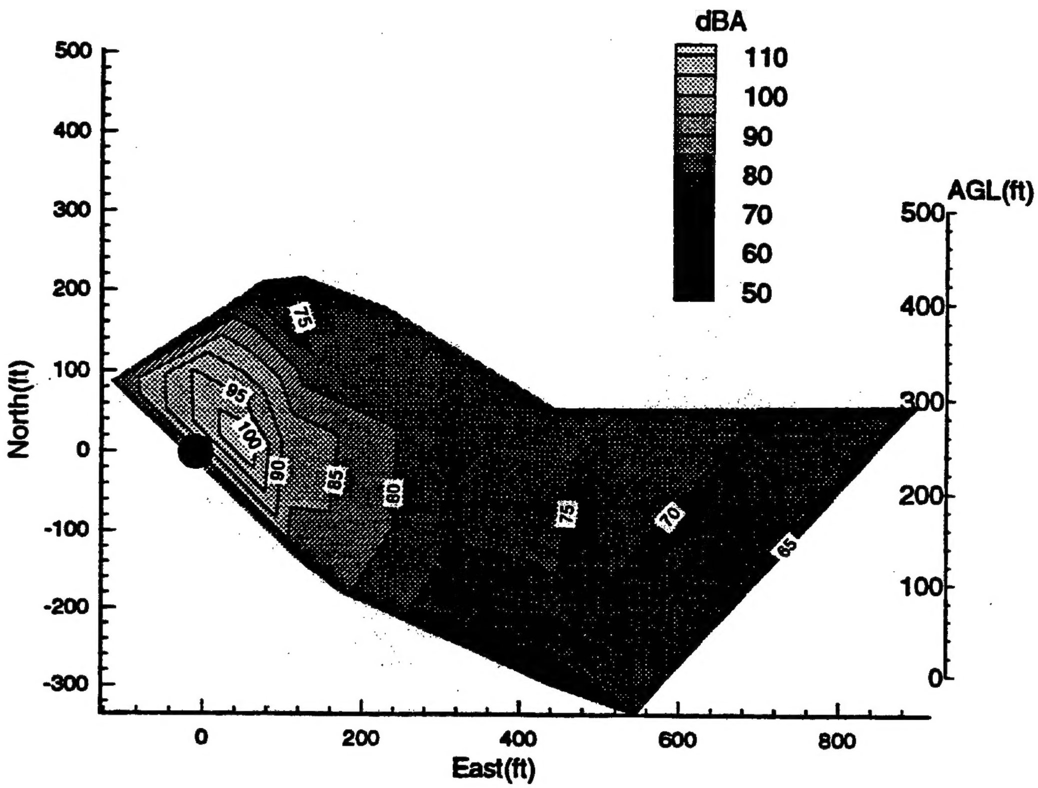


Figure 4.5: Noise contour for Run 1, Measurement Configuration A, helicopter on pad.

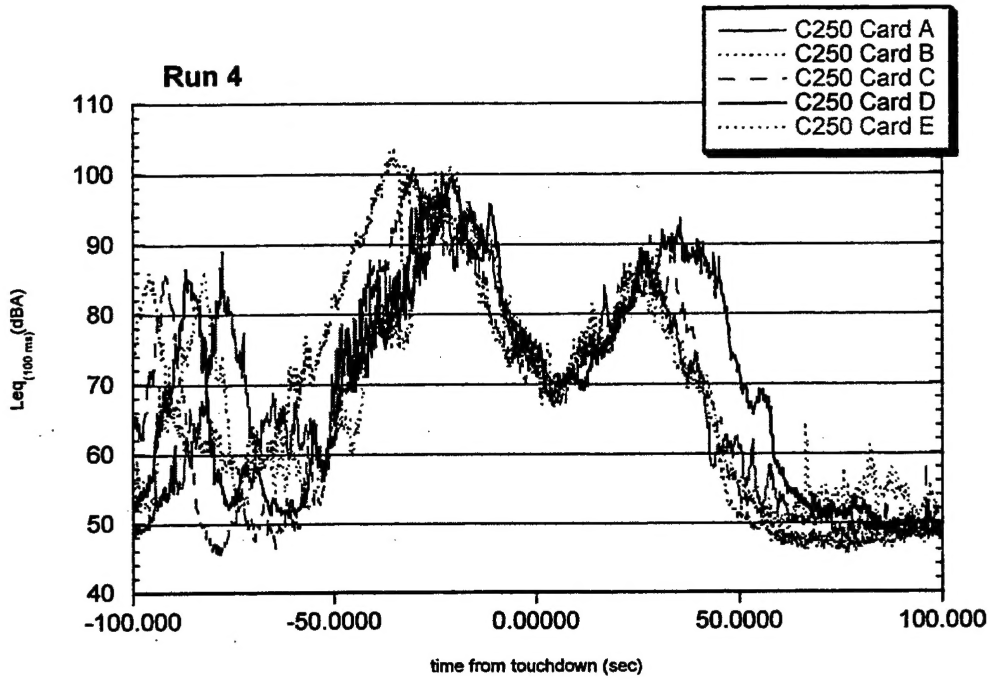


Figure 4.6: Comparison of the C250 location for Run 4, all configurations.

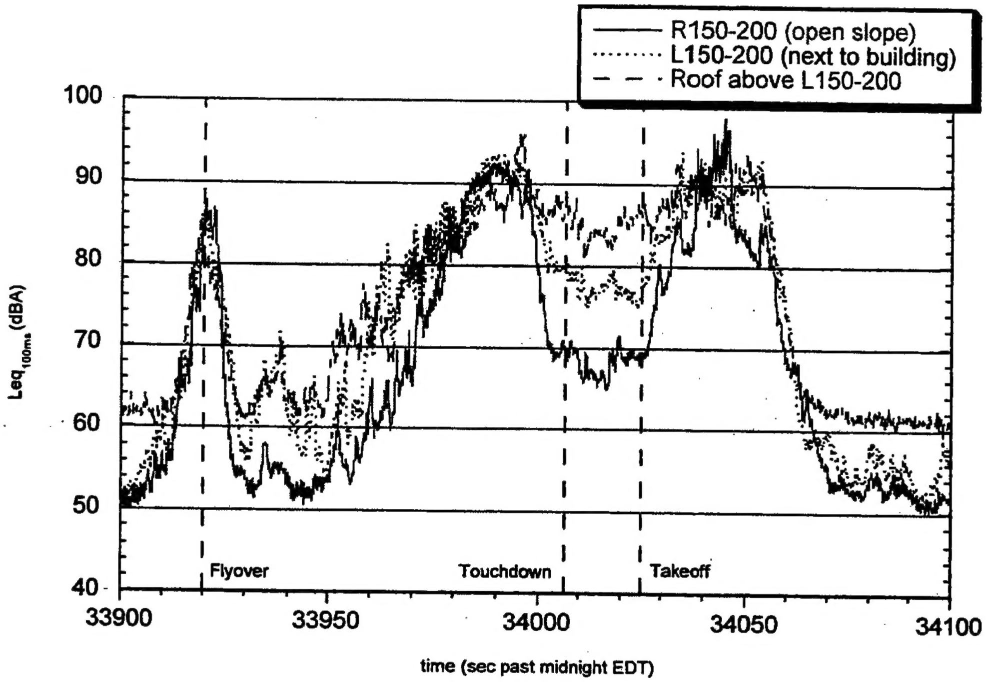


Figure 4.7: Comparison locations, Run 4, Configuration D.

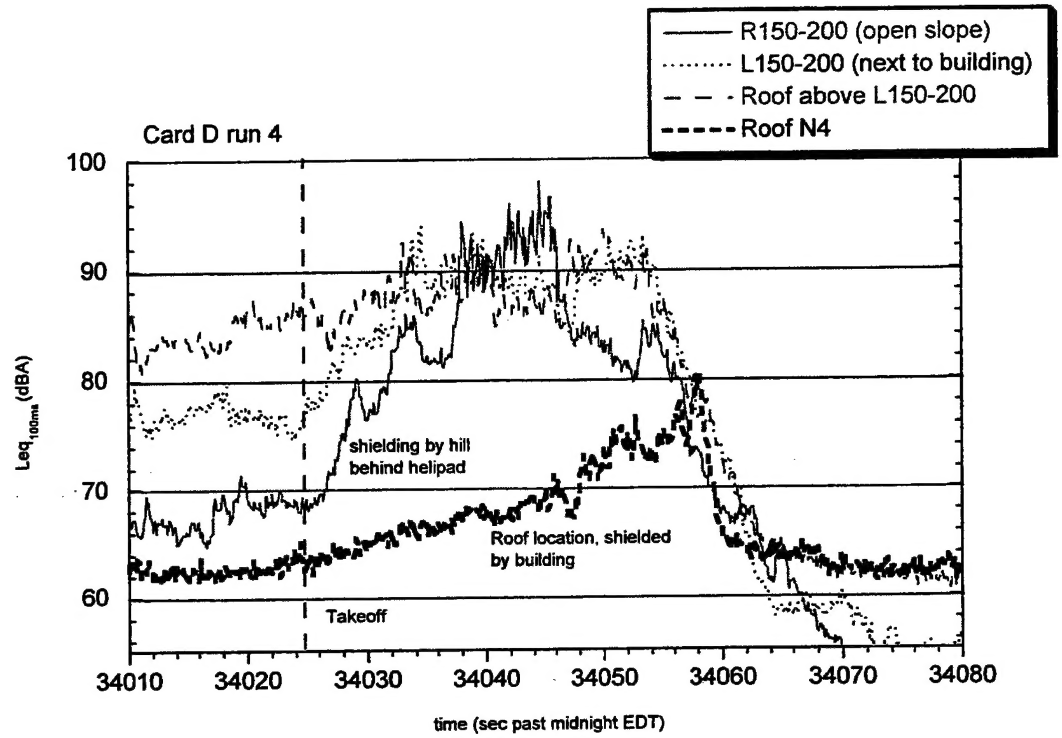


Figure 4.8: Comparison of locations, Run 4, Configuration D, takeoff.